BROOKHAVEN NATIONAL LABORATORY

Superconducting Magnet Division

Magnet Note

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Date: October 26, 2000

Topic No: 596-11 (AM-MD-297)

Topic: Magnet Measuring Results and Techniques

Title: Determining Magnetic Center in QH0102

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Determining Magnetic Center in QH0102

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1. Introduction:

To facilitate installation of QH0102 (GO2) at DESY, it is necessary to locate the magnetic center of the magnet with respect to outside fiducials located on the cryostat. This is carried out using a "survey antenna" system, initially developed for RHIC CQS assemblies. The center is determined only for the main quadrupole magnet. This system can not be used for the dipole layer, but could be used for the skew quadrupole and the sextupole layers. Since all the other layers are wound concentrically on the same support tube, the magnetic centers of those layers are expected to be essentially the same as that of the quadrupole layer. This is also supported by rotating coil data taken before the cold mass was assembled into the cryostat.

2. The Measurement System:

The measurement system consists of two parts– an "electromagnetic part" and an "optical survey" part. The electromagnetic part consists of a 23 cm long non-rotating coil (antenna) with two dipole and two quadrupole windings, a power supply, a set of HP3458 voltmeters to record the coil signals, and a computer to control the power supply, data acquisition and analysis. The non-rotating coil has survey targets on both ends of it which help to locate the position of the coil with respect to outside fiducials, as can be seen in Fig. 1. Oval spacers are attached to both ends of the antenna to keep it nominally centered in the oval beam tube of the magnet. The measurements are carried out at seven axial positions in the straight section. Regions too close to the ends are avoided.

The "optical survey" part consists of an alignment telescope, two Taylor-Hobson balls defining a line-of-sight, and a ManCat survey system with four theodolites for measuring the coordinates of any visible fiducials on the magnet. A CCD camera attached to the alignment telescope captures images of Taylor-Hobson balls and fiducials on the antenna, which are analyzed using software on the computer. The arrangement is shown schematically in Fig. 2.

The magnet is excited with a sinusoidal current waveform at a frequency of 20 Hz and 0.9 A peak amplitude. The resultant pick-up signals in the quadrupole and the dipole windings are analyzed to determine the quadrupole and the dipole terms, which give the offset of magnetic center with respect to the geometric center of the survey antenna. Further details of the system and analysis can be found in reference [1]. Since the position of the antenna with respect to the Taylor-Hobson balls is determined by looking at the antenna fiducials with the alignment telescope, one effectively obtains the magnetic center with respect to the line-of-sight defined by the Taylor-Hobson balls. By combining survey data on the magnet fiducials with those on the Taylor-Hobson balls, one finally obtains the magnetic center in a reference frame defined by the magnet fiducials.

Fig. 1   The survey antenna with fiducials and oval spacers.

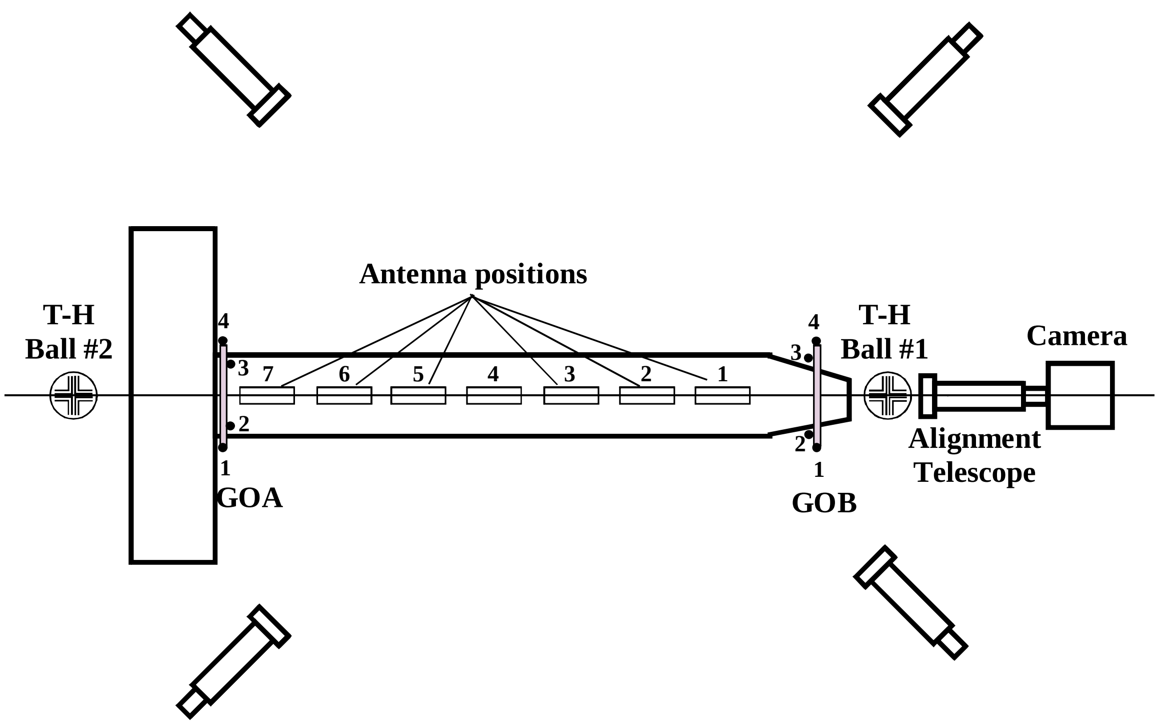

Fig. 2   The optical survey setup for antenna measurements (Top view).

3. The Magnet Fiducials:

Two survey target holders, GOA for the lead end and GOB for the non-lead end, were provided by DESY. Each of these holders contain four survey targets, which were named GOA1 through GOA4 and GOB1 through GOB4. The naming convention used by BNL is also indicated in Fig. 2.

The target holders are placed in a notch on either end of the cryostat, near the top. There is a similar notch at the bottom of the cryostat also, allowing one to place the holders upside down on the bottom surface, supported by small jacks. The four targets on each holder were also measured in this upside down position. The bottom four positions were labeled GOA5 through GOA8 and GOB5 through GOB8. The numbering was continued from 1-4 on each target in either a clockwise or counter-clockwise sequence.

The reproducibility of measurements on these targets was reasonably good, except for the dimension along the length of the magnet (~0.25 mm error). This error does not appear to be of any significance, since only the transverse dimensions are critical.

4. The Coordinate System:

A coordinate system tied to the magnet can be defined by using any suitable set of three targets chosen out of the eight. No preferred coordinate system was communicated by DESY. We have used a coordinate system that is very similar to that used for CQS assemblies in RHIC. In this system, the Z-axis is nearly vertical, pointing upwards, the positive Y-axis goes from the non-lead end to the lead end and runs nearly parallel to the magnet axis, and the X-axis is nearly horizontal, completing a right handed coordinate system.

The coordinate system is shown in more detail in Fig. 3. The origin is located at the point GOB1 on the non-lead end. The Y-axis is defined by the line joining GOA1 and GOB1, which is expected to be nearly parallel to the magnet axis. The X-axis is at right angles to this Y-axis, in the X-Y plane defined by the set of three points GOA1, GOB1 and GOB4, as shown in Fig. 3. Finally, the Z-axis is defined by a line perpendicular to this X-Y plane, pointing upwards.

5. Results for QH0102 Before Coordinate Transformation:

The “stand-alone” data from the survey antenna (before incorporating optical survey information from the magnet fiducials) gives the magnetic center in a coordinate system with the Y-axis along the line-of-sight defined by the two Taylor-Hobson balls. While this information alone is not very useful for installation purposes, it nevertheless gives accurate information on the straightness of the assembly.

Fig. 4, shows the variation of the X and Z coordinates of the magnetic center in QH0102 as a function of the axial position, Y, in two separate measurements. The origin for these data is located at the intersection of the plane of the beam tube flange on the non-lead end with the alignment telescope line-of-sight. A bow of about 0.60 mm in the horizontal direction and about 0.35 mm in the vertical direction is seen.

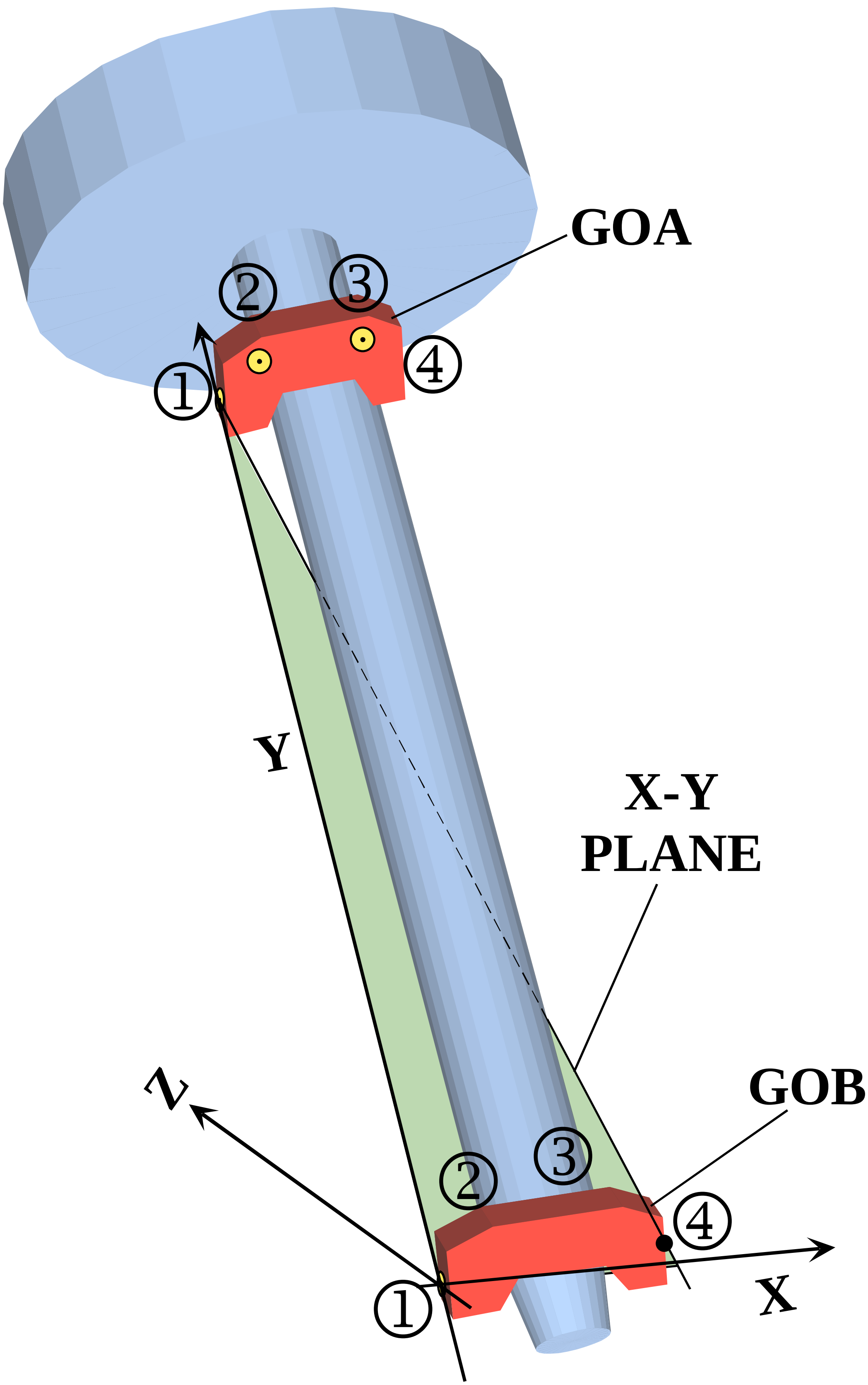

Fig. 3 The coordinate system.

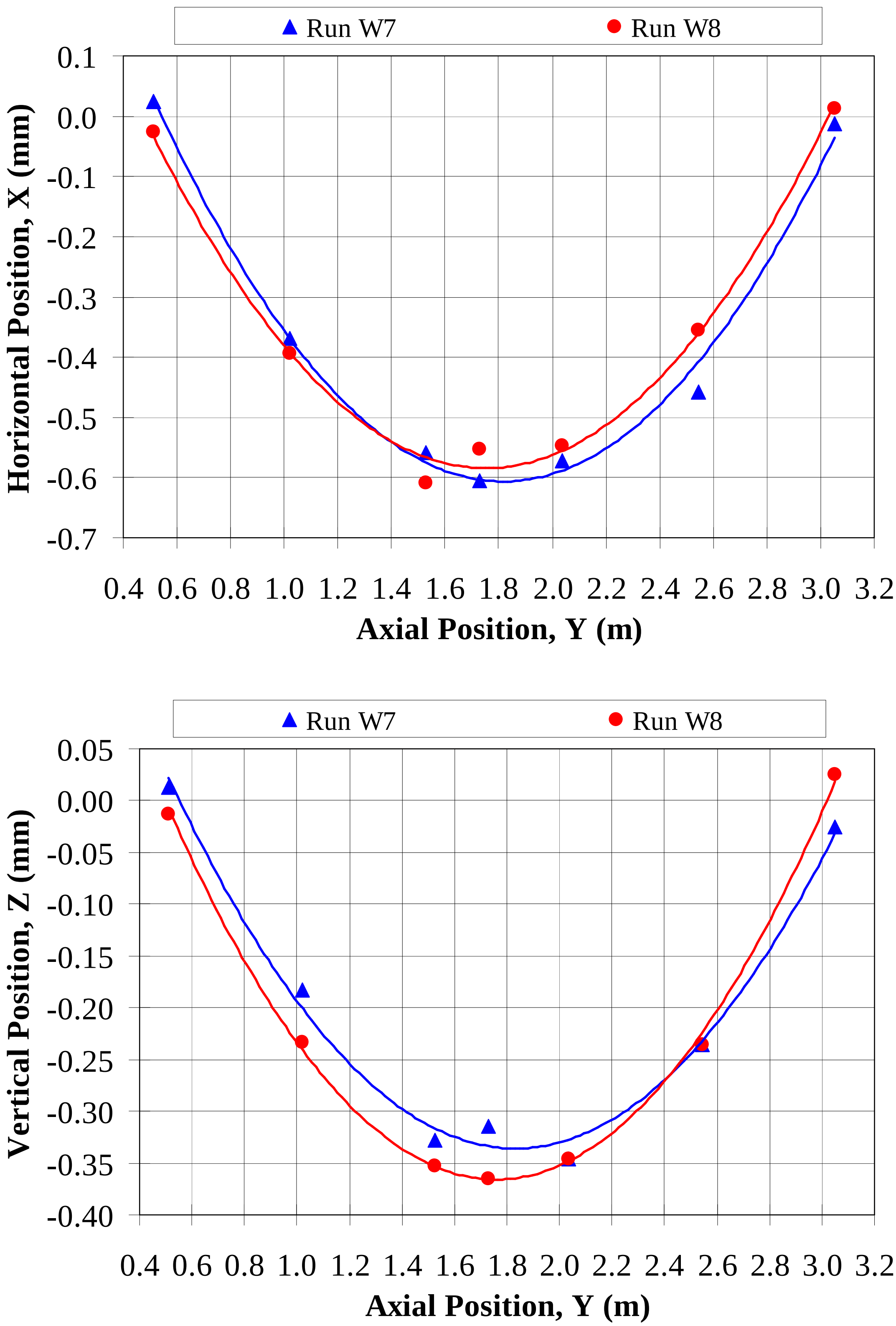

Fig. 4 The “stand-alone” antenna data in QH0102 main quadrupole.

6. Results for QH0102 After Coordinate Transformation:

An EXCEL macro has been written to accomplish the transformation of coordinates necessary to express all the raw data in the "magnet-fixed" frame described in Sec. 4. The macro first transforms the survey data using appropriate translations and rotations. It then uses the transformed coordinates of the Taylor-Hobson balls, THB1 and THB2 to obtain the rotations and translations to be applied to the raw antenna data. The transformation parameters are obtained by noting that the coordinates of THB1 and THB2 in the antenna frame are $(0, -|y_1|, 0)$ and $(0,|y_2|,0)$, where $y_1(y_2)$ is the distance between the non-lead end flange and THB1(THB2). A paste-on target, named PT1, was placed on the non-lead end flange and surveyed. A perpendicular is first drawn from PT1 to the line joining THB1 and THB2 and the point of intersection is determined. The distances from this intersection point to THB1 and THB2 give y_1 and y_2.

The coordinates of all the fiducial points after the transformation are given in Table 1. As can be seen, the origin is located at GOB1 (No. 10), the point GOA1 (No. 2) lies on the Y-axis, and the point GOB4 (No. 13) lies in the X-Y plane.

Table 1. Coordinates of all the fiducials in the "magnet-fixed" frame

Target No.	Target Name	X (mm)	Y (mm)	Z (mm)
1	**PT1**	126.766	–10.497	–89.822
2	**GOA1**	0.000	3384.954	0.000
3	**GOA2**	25.626	3371.932	90.171
4	**GOA3**	225.555	3371.561	91.517
5	**GOA4**	252.412	3384.553	1.670
6	**GOA5**	252.235	3384.645	–99.990
7	**GOA6**	225.661	3371.482	–189.838
8	**GOA7**	25.709	3371.526	–189.027
9	**GOA8**	–0.164	3384.700	–98.895
10	**GOB1**	0.000	0.000	0.000
11	**GOB2**	26.151	13.259	50.004
12	**GOB3**	226.171	13.486	49.962
13	**GOB4**	252.358	0.206	0.000
14	**GOB5**	252.248	0.126	–99.756
15	**GOB6**	225.990	13.263	–149.767
16	**GOB7**	26.014	13.335	–149.516
17	**GOB8**	–0.125	0.285	–99.474
18	**GOAR1**	–0.169	3384.685	0.544
19	**GOAR4**	252.306	3384.662	1.116
20	**GOBR1**	–0.091	0.251	0.001
21	**GOBR4**	252.300	0.236	0.029
22	**THB1**	126.858	–422.661	–49.717
23	**THB2**	126.487	4946.999	–50.782

The magnetic centers measured in two different runs are given in Table 2 and are also shown in Fig. 5. The run to run reproducibility is typically within 50 μm. The solid lines in Fig. 5 represent quadratic fits to data points from both the runs. The curvature of the magnetic axis in both the horizontal and the vertical directions can be seen once again.

Table 2. Magnetic centers in the “magnet-fixed” frame

Position No.	**Axial, Y (m)**	**Horizontal, X (mm)**			**Vertical, Z (mm)**		
		Run W7	**Run W8**	**Average**	**Run W7**	**Run W8**	**Average**
1	0.501	125.499	125.448	125.473	–49.722	–49.748	–49.735
2	1.009	125.057	125.032	125.044	–49.925	–49.976	–49.950
3	1.517	124.819	124.768	124.793	–50.076	–50.102	–50.089
4	1.720	124.754	124.805	124.779	–50.066	–50.117	–50.091
5	2.025	124.758	124.784	124.771	–50.101	–50.101	–50.101
6	2.533	124.825	124.927	124.876	–49.998	–49.998	–49.998
7	3.041	125.222	125.247	125.234	–49.794	–49.743	–49.769

The horizontal and the vertical coordinates of the magnetic center as a function of axial position are given by the fitted curves:

$$\left.\begin{aligned} X(\text{mm}) &= 126.079 - 1.3945\,y + 0.3664\,y^2 \\ Z(\text{mm}) &= -49.388 - 0.789\,y + 0.2176\,y^2 \end{aligned}\right\}\ (\,y \text{ in meters}) \qquad (1)$$

The axial center of the quadrupole magnet in this frame is at ~1.77 m. A magnetic length of 3.1 m implies the magnet extends from $y \sim 0.22$ m to $y \sim 3.32$ m. Integrating the right hand side of Eq. (1) over this range and dividing by the magnetic length, we get the “average” position of the magnetic center as:

$$\overline{X} = 125.052\ \text{mm};\quad \overline{Z} = -49.929\ \text{mm};\quad \overline{Y} \approx 1770\ \text{mm} \qquad (2)$$

Reference:

[1] Animesh Jain, *A Survey Antenna for Determining Magnetic Center*, Proc. 10th International Magnet Measurement Workshop (IMMW-10), Fermilab, October 13-16, 1997.

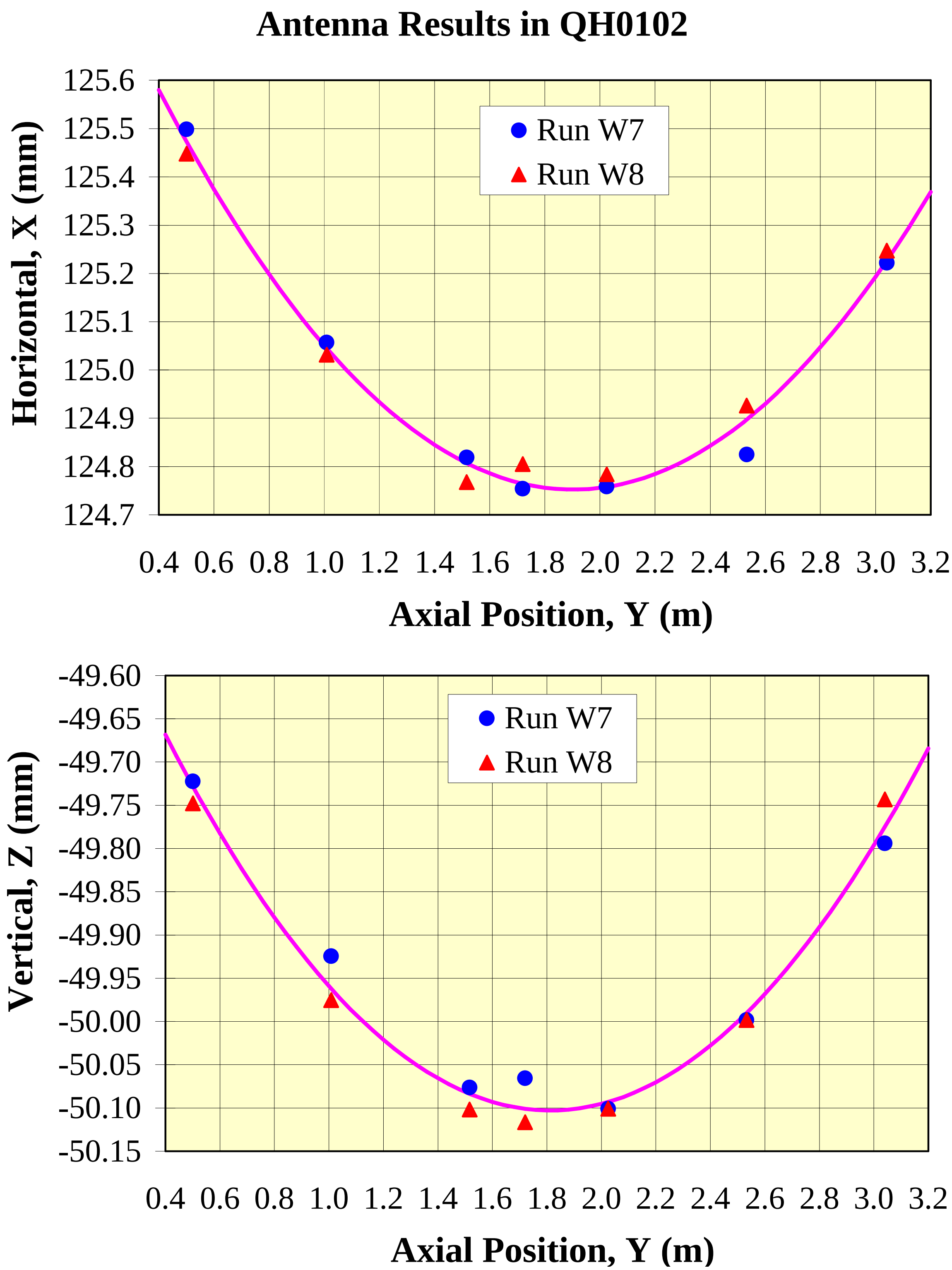

Fig. 5 Magnetic centers in QH0102 main quadrupole after coordinate transformation.